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Prospects of biodiesel from Jatropha in India: A review

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ABSTRACT

The increasing industrialization and modernization of the world has to a steep rise for the demand of petroleum products. Economic development in developing countries has led to huge increase in the energy demand. In India, the energy demand is increasing at a rate of 6.5% per annum. The crude oil demand of the country is met by import of about 80%. Thus the energy security has become a key issue for the nation as a whole. Petroleum-based fuels are limited. The finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these reserves are facing foreign exchange crises, mainly due to the import of crude oil. Hence it is necessary to look forward for alternative fuels, which can be produced from feedstocks available within the country.

Biodiesel, an ecofriendly and renewable fuel substitute for diesel has been getting the attention of researchers/scientists of all over the world. The R & D has indicated that up to B20, there is no need of modification and little work is available related to suitability and sustainability of biodiesel production from Jatropha as non-edible oil sources. In addition, the use of vegetable oil as fuel is less polluting than petroleum fuels. The basic problem with biodiesel is that it is more prone to oxidation resulting in the increase in viscosity of biodiesel with respect to time which in turn leads to piston sticking, gum formation and fuel atomization problems.

The report is an attempt to present the prevailing fossil fuel scenario with respect to petroleum diesel, fuel properties of biodiesel resources for biodiesel production, processes for its production, purification, etc. Lastly, an introduction of stability of biodiesel will also be presented.

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1. Introduction

Energy is a basic requirement for economic development. Every sector of Indian economy—agriculture, industry transport, commercial and domestic needs input of energy. The economic development plans implemented since independence have necessarily required increasing amount of energy. As a result consumption of energy in all forms has been steadily rising all over the country. This growing consumption of energy has also resulted in the country becoming increasingly dependent on fossil fuels such as coal, oil and gas. Rising prices of oil and gas and potential shortage in future lead to concern about the security of energy supply needed to sustain our economic growth. Increased use of fossil fuels also causes environmental problems both locally and globally.

In India, the consumption of crude oil was about 184.68 MT for the year 2007–2008, but 80% of this production was met by import [1]. The share of high-speed diesel was about 36% in the above production. The rate of energy consumption is increasing at the rate of 6.5% per annum while reserves for petroleum oil are decreasing day by day.

India's share of crude oil production is about 1% of total world crude oil production while in consumption; its share is about 3.1% of total world consumption [2]. The import of crude oil has increased from 63% in 1971 to 80% in 2007–2008. The demand of petroleum oil and its production in the country is given in Table 1.

The above table indicates that India imports heavy amount of crude oils for its domestic consumption and consequently pay huge foreign exchange for it. The demand of high-speed diesel (HSD) is projected to grow from 39.81 MT in 2001–2001 to 52.32 MT in 2007–2008 at the rate of 5.6% per annum [1,3].

1.1. Oil as resource of biodiesel

The possibilities of production of biodiesel from edible oil resources in India is almost impossible, as primary need is to first meet the demand of edible oil that is already imported. India accounts for 9.3% of world's total oil seed production and contributes as the fourth largest edible oil producing country. Even then, about 46% of edible oil is imported for catering the domestic needs. Table 2 gives the production and consumption of edible oil for country.

The above table indicates that India imports about 40–50% edible oil of its domestic requirement and therefore, it is not possible to divert the edible oil resources for biodiesel production in the country. So the non-edible oil resources like Jatropha, pongamia, etc., seems to be the only possibility for biodiesel production in the country.

As per Government of India survey, out of total land area, 60 Mha are classified as waste and degraded land. India has third largest road network in Asia having length about 3 million km the sides of which can be used for growing the Jatropha and Karanjia crops and oil can be converted into biodiesel. India has railway network of 63,140 km and land along the track can be easily used for cultivation of *Jatropha curcas* to check the soil erosion and to improve fertility in addition to oil production. The future demand for biodiesel in India is given in Table 3.

Table 1
Crude oil consumption (MT) in India [1,3].

S. No.	Year	Indigenous production	Import	Total	Import as % of total demand	Import value in (Crores)
1	1971	6.8	11.7	18.5	63	107
2	1981	10.5	16.2	26.7	61	3349
3	1991	33.0	20.7	53.7	39	6118
4	2001	32.0	57.9	89.9	64	30,695
5	2003–2004	33.4	90.4	123.8	73	81,000
6	2004–2005	33.98	100.0	133.98	75	121,500
7	2005–2006	32.19	105.0	137.19	77	173,076
8	2006–2007	33.99	120.0	153.99	78	492,000
9	2007–2008	36.68	148.0	184.68	80	606,800

Table 2
Production and consumption of edible oil (lakh T) [4].

S. No.	Oil year	Production of oil seeds	Net availability of oil from domestic sources	Import of edible oil	Consumption of edible oil
1	1998–1999	247.48	69.60	26.22	95.82
2	1999–2000	207.15	60.15	41.96	102.11
3	2000–2001	184.40	54.90	41.86	96.76
4	2001–2002	206.63	61.46	43.22	104.68
5	2002–2003	150.58	47.28	43.65	90.93
6	2003–2004	251.42	71.09	52.95	124.04
7	2004–2005	248.42	73.10	44.0	117.10
8	2005–2006	254.56	78.30	57.9	136.2
9	2006–2007	258.48	80.5	64.2	144.7
10	2007–2008	276.22	85.4	72.48	157.88

Table 3
Biodiesel demand in India [3].

S. No	Year	Diesel demand (MT)	5% blend (MT)	Area (Mha)	10% blend (MT)	Area (Mha)	20% blend (MT)	Area (Mha)
1	2006–2007	52.33	2.62	2.19	5.23	4.38	10.47	8.76
2	2011–2012	66.40	3.35	2.79	6.69	5.58	13.38	11.19

Table 4
Production of non-edible oils in India [5].

S. No.	Botanical name	Local name	Annual productivity (T)
1	*Jatropha curcas*	Ratanjyot	15,000
2	*Pongamia pinnata*	Karanja	55,000
3	*Schleichera oleosa*	Kusum	25,000
4	*Azadirachta indica*	Neem	100,000
5	*Modhuca indica*	Mahua	180,000

The above table indicates that by the year 2011–2012, about 13.38 MT of diesel could be saved if B_{20} blend is utilized. This will ensure sustainable fuel availability with secured environmental conditions.

As per the report of the committee on Biofuel, the estimated demand of HSD in 2006–2007 was 52.3 MT, requiring 10.5 MT of biodiesel and plantation of *Jatropha curcas* over about 8.8 million ha of land. By the end of eleventh plan (2011–2012), the demand for HSD shall be 66.9 MT, requiring 13.38 MT of biodiesel and plantation of *Jatropha curcas* over about 11.2 million ha of land [2].

1.2. Non-edible oil resources

It is estimated that the potential availability of such oils in India is about 1 million T per year. The most abundant oil sources are Sal, Mahua, Neem, Pongamia and Jatropha oil. Based on extensive research, Jatropha and Pongamia have been identified as the potential feedstocks for biodiesel production in near future. Table 4 gives the oil productivity of these most important non-edible oils resources in India.

2. Jatropha as an option of transport fuel

Jatropha curcas is a drought-resistant perennial, growing well in marginal/poor soil. It is easy to establish, grows relatively quickly and lives, producing seeds for 50 years. Jatropha the wonder plant produces seeds with an oil content of 37%. The oil can be combusted as fuel without being refined. It burns with clear smoke-free flame, tested successfully as fuel for simple diesel engine. It is found to be growing in many parts of the country, rugged in nature and can survive with minimum inputs and easy to propagate [6].

Jatropha curcas is becoming the future source of biodiesel for India. The planning commission, Government of India, has initiated an ambitious program of growing *Jatropha curcas* on waste land for biodiesel production. Among the various oil seeds, *Jatropha curcas* has been found more suitable for biodiesel production on the basis of various characteristics. The cultivation of jatropha is possible under stress condition and the oil of these species having various characteristics is more suitable for biodiesel production. *jatropha curcas* has been scientifically developed to give better yield and productivity of oil. Jatropha oil has higher cetane no. (51) compared to other oils, which is compared to diesel (46–50) and make it an ideal alternative fuel and requires no modification in the engine. A study has been done on biodiesel from Jatropha oil as a transport fuel for UP state and found that this will save foreign exchange and reduce CO_2 emission [29].

2.1. Advantages of cultivation of Jatropha curcas

- Jatropha can be grown in arid zones (20 cm rainfall) as well as in higher rainfall zones and even on land with their soil cover.
- It is a quick yielding species even in adverse land situations, viz., degraded and barren lands under forest and non-forest use, dry and drought prone area, marginal lands even an alkaline soils and also as agro forestry crops.
- Jatropha can be a good plant material for eco-restoration in all types of wasteland.
- Jatropha grows readily from plant cuttings or seeds up to the left of 3–5 m.
- Jatropha is not considered good forage material.
- The plant is highly pest and disease resistant.
- Jatropha removes carbon from the atmosphere stores it in the woody tissues and assists in the build up of soil carbon.

2.2. Biodiesel vs. land requirement in India

As India is deficient in edible oils, non-edible oils become the main choice for biodiesel. Generally, a blend of 5–20% is used in India (B_5–B_{20}). Indian oil corporation (IOC) has taken up Research and Development work to establish the parameters for the production and use of biodiesel in its R & D centre at Faridabad. Research is also carried out in Kumaraguru College of Technology to marginally alter the engine parameters to suit the Indian Jatropha seeds and to minimize the cost of transesterification. Table 5 gives an idea about the land requirement for growing resource in future.

Table 6 shows that by the year 2020, against a total requirement of diesel of 162.67 MT, the 32.53 MT biodiesel (B_{20}) shall be required. For achieving this target a land area of about 54.22 Mha shall be required for the cultivation of Jatropha and other oil seed crops. As mentioned earlier about 60 Mha of waste land including the sides of roads and railway tracks, can be used for cultivation of Jatropha plants as well as other crops.

However, the land being cultivated for Jatropha in various states is given in Table 7, which shows that the maximum Jatropha cultivation is being done in the state of Maharashtra followed by Gujarat, Tamil Nadu and Rajasthan.

2.3. Productivity of Jatropha plantation

Jatropha plant bears fruits from 2nd year of its plantation and the economic yield stabilizers from 4th or 5th year onwards. The

Table 5
Area coverage vs. blending requirements [7].

Year	Diesel demand (MT)	Biodiesel at 5% (MT)	Area for 5% (Mha)	Biodiesel at 10% (MT)	Area for 10% (Mha)	Biodiesel at 20% (MT)	Area for 20% (Mha)
2005–2006	49.56	2.48	2.07	4.96	4.14	9.91	8.28
2006–2007	52.33	2.62	2.19	5.23	4.38	10.47	8.76
2010–2011	66.90	5.02	8.37	10.0	16.7	20.1	33.5

Table 6
The biodiesel and land requirement in India for future [7].

Year	Diesel demand (MT)	Biodiesel requirement (MT)			Seed requirement (MT)			Area requirement (Mha)		
		BD_5	BD_{10}	BD_{20}	BD_5	BD_{10}	BD_{20}	BD_5	BD_{10}	BD_{20}
2007–2008	60.18	3.01	6.02	12.0	10.0	20.0	40.1	5.01	10.0	21.0
2008–2009	90.27	4.51	9.03	18.0	15.0	30.1	60.1	7.52	15.0	30.0
2009–2010	95.23	4.76	9.52	19.0	15.8	31.7	63.5	7.94	15.8	31.7
2010–2011	100.47	5.02	10.0	20.1	16.7	33.5	66.9	8.37	16.7	33.5
2011–2012	106.00	5.30	10.6	21.2	17.6	35.3	70.6	8.83	17.6	35.3
2012–2013	111.83	5.59	11.1	22.3	18.6	37.2	74.5	9.32	18.6	37.2
2013–2014	117.98	5.90	11.8	23.6	19.6	39.3	78.6	9.93	19.6	39.3
2014–2015	124.47	6.22	12.4	24.9	20.7	41.5	82.9	10.3	20.7	41.5
2015–2016	131.31	6.57	13.3	26.2	21.9	43.7	87.5	10.9	21.9	43.7
2016–2017	138.54	6.93	13.8	27.7	23.1	46.1	92.6	11.5	23.1	46.1
2017–2018	146.16	7.31	14.6	29.2	24.3	48.7	97.4	12.1	24.3	48.7
2018–2019	154.19	7.71	15.4	30.8	25.7	51.4	102	12.8	25.7	51.4
2019–2020	162.67	8.13	16.2	32.5	27.1	54.2	108	13.5	21.1	54.2

plant has an average life with effective yield up to 50 years. Jatropha gives about 2 kg of seed per plant in relatively poor soils such as in kutch (Gujarat). The seed yields have been reported as 0.75–1.00 kg per plants thus the economic yield can be considered to range between 0.75 and 2.00 kg/plant and 4.00 and 6.00 MT per hectare per year depending on agro-climatic zone and agriculture practices. One hectare of plantation on average soil will give 1.6 MT oil [7] as shown in Table 8.

The cost of plantation has been estimated as Rs. 20,000/- per hectare inclusive of plant material, maintenance for 1 year, training overheads, etc., includes elements such as site preparation, planting management, fertilizers, irrigation, deseeding and plant protection seed collection, seed processing, etc., for 1 year, i.e., the stage when it will start bearing fruits Jatropha oil composition is given in Table 9.

Table 7
Land area under cultivation of Jatropha in various states of India [5].

State	Area (ha)	% of total land
Andhra Pradesh	260	2.63
Bihar	110	1.11
Chattisgarh	650	6.58
Delhi	665	6.63
Gujarat	1140	11.54
Goa	10	0.10
Haryana	520	5.26
Jharkhand	200	2.02
Karnataka	120	1.21
Kerala	50	0.5
Madhya Pradesh	84	0.85
Maharashtra	1310	13.26
Manipur	200	2.03
Meghalaya	200	2.03
Mizoram	300	0.30
Nagaland	240	2.43
Rajasthan	715	7.24
Tamilnadu	960	9.72
Uttar Pradesh	633	6.41
Uttarakhand	650	6.58
West Bengal	100	1.01
Total	9878	100

Table 8
Productivity of Jatropha plantation.

S. No.	1
Seeds/hactare (MT)	4–6
Oil/hectare (MT)	1.5–2
Biodiesel/hectare (MT)	1.35–1.8
Cost of plantation/hectare (Rs.)	20,000

3. Fuel properties of straight vegetable oil (SVO)

The fuel properties of vegetable oils as given in Table 10 [8,9] indicates that the kinematic viscosity of vegetable oils varies in the range of 30–40 cSt at 38 °C. The high viscosity of these oils is due to their large molecular weight and chemical structure. Vegetable oils have high molecular weight in the range of 600–900, which is three times higher than diesel fuel. The flash point of vegetable oil is very high (above 200 °C). The higher heating values of these oils are in the range of 39–40 MJ/kg that is low compared to diesel fuel (about 45 MJ/kg). The presence of chemical bound oxygen in vegetable oils lowers their heating values by about 13%. The cetane numbers are in the range of 32–40. The iodine value ranges from 0 to 200 depending upon unsaturation. The cloud and pour points are higher than that of diesel.

As Table 10 shows that the viscosity of vegetable oils is in the range from 40 to 50 cSt which is almost 20–25 times higher than diesel. Therefore it is difficult to use vegetable oils directly in engine due to piston ring sticking, gum formation and fuel automization problem. This needs to go for modification in vegetable oils to reduce the viscosity. The vegetable oils have higher the flash point and lower the calorific value than diesel.

4. Method for modification of straight vegetable oil (SVO)

In view of the problem of direct use of SVO and frequent periodic overhauling of engine, it is worthwhile to employ modification methods that help to reduce the viscosity of oil/give the product suitable as engine fuel. Many standardized procedures are available for the modification of SVO [75]. The commonly used methods are discussed in the following sections.

4.1. Blending

Vegetable oil can be directly mixed with diesel fuel and may be used for running an engine. The blending of SVO with diesel fuel was experimented successfully. It has been proved that the use of 100% SVO was also possible with some minor modifications in the fuel system [10]. The high fuel caused the major problems associated with the use of pure vegetable oils as fuel viscosity in compression ignition engines. Micro-emulsification, pyrolysis and transesterification are the methods used to solve the problems encountered due to high fuel viscosity.

4.2. Micro-emulsification

To solve the problem of high viscosity of SVO, micro-emulsions with solvents such as methanol, ethanol and butanol have been

Table 9
Composition of Jatropha oil [8].

Fatty acid	Formula	Systematic name	Structure	Net (%)
Lauric acid	$C_{12}H_{24}O_2$	Dodecanoic acid	C_{12}	–
Myristic acid	$C_{14}H_{28}O_2$	Tetradecanoic acid	C_{14}	0–0.1
Palmitic acid	$C_{16}H_{32}O_2$	Hexadecanoic acid	C_{16}	14.1–15.3
Palmitolileic acid	$C_{16}H_{30}O_2$	Cis-9-hexadecnoic acid	$C_{16:1}$	0–1.3
Stearic acid	$C_{18}H_{38}O_2$	Octadecanoic acid	C_{18}	3.7–9.8
Oleic acid	$C_{18}H_{34}O_2$	Cis-9-Octadecanoic acid	$C_{18:1}$	34.3–45.8
Linoleic acid	$C_{18}H_{32}O_2$	Cis-9-cis-12-Octadecadeneoic acid	$C_{18:2}$	29.0–44.2
Linolenic acid	$C_{18}H_{30}O_2$	Cis-6-cis-9-cis-12-octadecatrienoic acid	$C_{18:3}$	0–0.3
Arachidice acid	$C_{20}H_{40}O_2$	Eicosanoic acid	C_{20}	0–0.3
Behenic acid	$C_{22}H_{44}O_2$	Docosanoic acid	C_{22}	0–0.2
Gadoleic acid	$C_{24}H_{48}O_2$		C_{24}	14
Saturates	–	–	–	21.1
Unsaturates	–	–	–	78.9

Table 10
Fuel properties of vegetable oil [8,9].

Vegetable oils	Cetane number	Heating values (MJ/kg)	Cloud point (°C)	Pour point (°C)	Kinematic viscosity (cSt at 38 °C)	Flash point	Specific gravity at 15 °C
Corn	37.6	39.5	−1.1	−40.0	34.9	277	0.9095
Cottonseed	41.8	39.5	1.7	−15.0	33.5	234	0.9148
Rapeseed	37.6	39.7	−3.9	−31.7	37.0	246	0.9115
Safflower	41.3	39.5	18.3	−6.7	31.3	260	0.9144
Sesame	40.2	39.3	−3.9	9.4	35.5	260	0.9133
Soybean	37.9	39.6	−3.9	−12.2	32.6	254	0.9138
Sunflower	37.1	39.6	7.2	−15.0	33.9	274	0.9161
Palm	42.0	39.5	31.0	–	39.6	267	0.9180
Jatropha	40–45	39–40	–	–	55 at 30 °C	240	0.912
Diesel	40–55	42	−15 to −5	−33 to −15	1.3–4.1	60–80	0.82–0.86

used. A micro emulsion is defined as the colloidal equilibrium dispersion of optically isotropic fluid. These can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. All micro-emulsions with butanol, hexanol and octanol can meet the maximum viscosity limitation for diesel engines.

4.3. Cracking

Cracking is the process of conversion of one substance into another by means of heat or with the aid of catalyst. It involves heating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules. The pyrolyzed material can be vegetable oils, animal fats, natural fatty acids and methyl esters of fatty acids. The pyrolysis of fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum. Since World War I, many investigators have studied the pyrolysis of vegetable oil to obtain products suitable for engine fuel application. Tung oil was saponified with lime and then thermally cracked to yield crude oil, which was refined to produce diesel fuel and small amounts of gasoline and kerosene.

4.4. Transesterification

We shall confine to the transesterification only.

Transesterification is the most common method of converting oil into biodiesel that can be used directly or as blends with diesel in diesel engine. It is also called alcoholysis, is displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis, except that an alcohol is used instead of water. This process has been widely used to reduce the viscosity of triglycerides [30,31].

A transesterification reaction is represented in Fig. 1. A catalyst is usually used to speed up the reaction that may be basic, acid or enzymatic in nature.

The entire transesterification can be represented by three steps.

Transesterification is a method of transforming of an ester into another when a vegetable oil is reacted with methanol in the preserve of catalyst to give methyl ester also biodiesel and amount of glycerin.

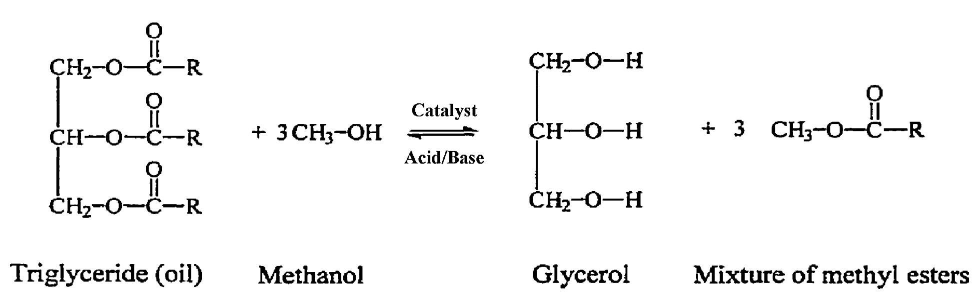

Fig. 1. Transesterification reaction.

Table 11
Biodiesel properties as fuel in different standards [6].

S.No.	Parameter	Austria ON	India BIS	France general official	Germany DIN	Italy UNI	USA ASTM
1	Density at 15 °C (g/cm^3)	0.85–0.89	0.87–0.89	0.87–0.89	0.875–0.89	0.86–0.90	0.88
2	Viscosity at 40 °C (mm^2/s)	3.5–5	1.9–6	3.5–5	3.5–5	3.5–5	1.96
3	Flash point (°C)	100	130	100	110	100	130
4	Pour point (°C)	–	–	10	–	1–5	15–18
5	Cetane number	≥49	≥40	≥49	≥49	–	≥47
6	Neutralization number (mgKOH/g)	≤0.8	≤0.5	≤0.5	≤0.5	≤0.5	≤0.8
7	Carbon residue (%)	≤0.05	≤0.05	–	≤0.05	–	≤0.05

4.4.1. Factors affecting the transesterification reactions

The most important variables that influence the transesterification reaction are:

- Reaction temperature.
- Ratio of alcohol to vegetable oil.
- Catalyst.
- Mixing intensity.
- Purity of reactants.

4.4.2. Types of transesterification

4.4.2.1. Acid catalyzed transesterification. When the amount of FFA contents in the oil is more than 1%, acid is used to catalyze the transesterification reaction. This is known as acid catalyzed esterification reaction, used to reduce FFA contents and increase the yield of alkyl esters.

4.4.2.2. Base catalyzed transesterification. When base is used to catalyze the transesterification reaction, it is known as base catalyst transesterification reaction. It is used when the amount of FFA contents are less than 1%. In this step, conversion of triglycerides into alkyl ester and glycerol occur. The lighter layer (biodiesel) is separated from heavier glycerol phase by separation. The lighter biodiesel is removed, washed with water, dried over anhydrous sodium sulphate and can be used directly as engine fuel in diesel engines.

5. Standards for comparing biodiesel quality

The countries like Germany, Italy, France, USA, etc., have developed their own biodiesel standards. However, an Indian standard under the name IS: 15607 is also being developed. Usually ASTM standards are followed all over the world. All above stated standards are reported in Table 11, which shows the limiting values of viscosity, flash point and acid value in ASTM standard is slightly higher than DIN standards. The limiting value of carbon residue is almost same for the entire above standards. Among the general parameters for biodiesel, the viscosity controls the characteristics if the injection from the diesel engine. The viscosity of fatty acid methyl ester can go very high levels and hence it is important to control it within the acceptable level to avoid negative impacts on fuel injector system performance. Therefore, the viscosity specifications proposed are nearly same as that of the diesel fuel.

6. Advantages of biodiesel

The following are the advantages of using biodiesel as substitute of diesel:

(i) Biodiesel is a green liquid fuel free from environmental problem as it emits emissions compared to diesel.
(ii) Biodiesel may not require engine modification up to B20. However, higher blends may need some minor modification.
(iii) Biodiesel is cheaper than diesel and can be a ‘‘on farm fuel’’ where the farmer can grow the seed oil crops, produced biodiesel and can use in the field itself.
(iv) Biodiesel can make the vehicle perform better as it has a cetane number of over 100 which is a measure of the quality of the fuel’s ignition.
(v) Owing to the clarity and the purity of biodiesel it can be used without adding additional lubricant unlike diesel engine.
(vi) Biodiesel reduces the environmental effect of a waste product. Because biodiesel is made out of waste products itself, it does not contribute to nature’s garbage at all. Biodiesel can be made out of used cooking oils and lards. So instead of throwing these substances away, the ability to turn them into biodiesel becomes more than welcome.
(vii) Biodiesel is energy efficient. If the production of biodiesel is compared with the production of the regular type, producing the latter consumes more energy. Biodiesel does not need to be drilled, transported, or refined like petroleum diesel. Producing biodiesel is easier and is less time consuming.
(viii) Biodiesel is produced locally. A locally produced fuel will be more cost efficient. There is no need to pay tariffs or similar taxes to the countries from which oil and petroleum diesel is sourced. Every country has the ability to produce biodiesel.

7. Disadvantages of biodiesel

(i) Low calorific value than diesel.
(ii) Higher pour and cloud point.
(iii) Higher NO_x emission.
(iv) Corrosive nature against copper and brass.
(v) Low volatility.

8. Comparison of emissions from biodiesel and diesel

The literature has reported that the engine operation on biodiesel mixed with diesel gave lower emission than diesel fuel expect in case of NO_X. It is observed that in case of NO_X, there is increase in 2% NO_X with B20 use and 10% with B100 use. The composition of emission of biodiesel and diesel is given in Table 12.

The above table shows that all emissions associated with biodiesel use are lower than diesel except NO_X. The higher of NO_X emission could be reduced either by slight retard of injection timing (1–5 degree) or by use of catalytic converter. The life cycle analysis of biodiesel shows that the reduction in CO_2 emission is

Table 12
Emission comparison of biodiesel and diesel [12].

S. No.	Emission type	B_{100}	B_{20}
1	Hydrocarbon (HC)	−67%	−20%
2	CO	−48%	−12%
3	Particulate matter (PM)	−47%	−2%
4	NO_X	+10%	+2%
5	SO_2	−100%	−20%
6	PAH	−80%	−13%

about 16% with B_{20} and 72% with B_{100} use on per liter combustion basis [11,12].

9. Performance of diesel engine with biodiesel and its blends with diesel

Biodiesel showed it's satisfactorily performance during diesel engine operation. The use of B_{20} in diesel engine provides almost same fuel economy as with diesel fuel. Due to high lubricity in nature, it provides less wear and tear in engine component. Many studies on the performances and emission of compression ignition engines, fuelled with pure biodiesel and blends with diesel oil have been performed and are reported in the literature. The presence of oxygen in the biodiesel leads to more complete combustion, resulting in lower emission in NO_X emission has been measured due to higher temperature.

A study has dealt in AHEC, IIT Roorkee with the production of biodiesel from Jatropha oil and performance evaluation of 2 kVA DG set on blends of biodiesel and diesel at various loads. The brake thermal efficiency is found higher up to B_{30} in comparison to diesel while BTE of B_{100} (24%) was almost equals to diesel (24.5%) for JOME. While the brake specific fuel consumption for B_{100} was 14.8% higher than diesel for biodiesel from Jatropha oil at full load, thereby indicating the use of 100% biodiesel can produce same output of energy using higher amount of biodiesel and therefore it deserve to become the "On Farmer Fuel" where farmer can grow his own resource, convert to biodiesel and use in agricultural sets itself without the need of any diesel for blending [13].

The variation of brake thermal efficiency is shown in Fig. 2, which indicates that the brake thermal efficiency of JOME (24%) is almost same as that of diesel at full load.

The brake thermal efficiency for biodiesel for all blends range (from B_{10} to B_{100}) was found almost comparable to that of diesel fuel. Perhaps due to higher cetane number and inherent presence of oxygen in the biodiesel produced better combustion. In addition the JOME and blends have lower viscosity and density than SVO. The reduction in viscosity of JOME leads to improved atomization, fuel vaporization and combustion. The ignition delay time is also close to diesel with ester as the cetane rating is higher. The brake thermal efficiency for B_{10} (25.8%), B_{20} (25.2%) and B_{30} (24.6%) was found about 1.3%, 0.7% and 0.1% higher than diesel, respectively. The reason for higher efficiency up to B_{30} may be because of better combustion due to inherent oxygen and higher cetane number. Beyond B_{30}, the lower calorific value and higher viscosity might be dominating factor responsible for poor atomization of fuel in the engine cylinder.

The variation of brake thermal efficiency of various blends of Jatropha oil and diesel is shown in Fig. 3, which indicates that the Brake Thermal Efficiency of blend of Jatropha oil and diesel (21.7%) is almost 2.8% less than that of diesel at full load.

The reason may the lower calorific value and higher viscosity might be dominating factor over inherent oxygen and higher cetane number. Due to higher viscosity, the atomization of fuel has not been as good as it is for lower viscosity at same level of pressure developed by injector pump.

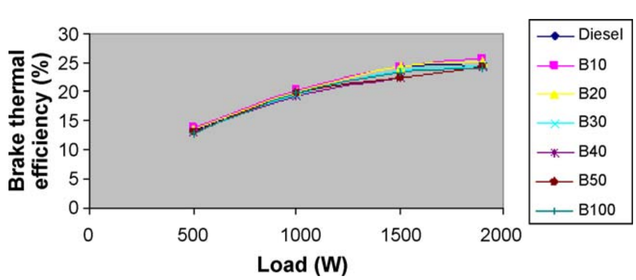

Fig. 2. Variation in BTE with load for different blends of Jatropha biodiesel with diesel.

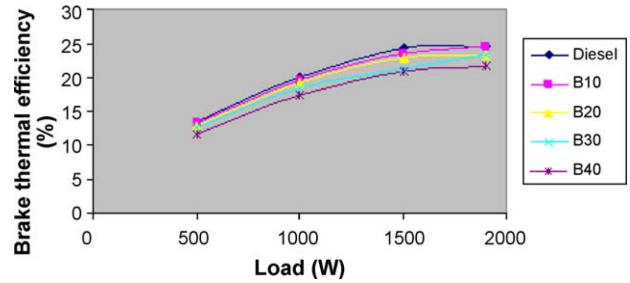

Fig. 3. Variation in BTE with load for different blends of Jatropha oil with diesel.

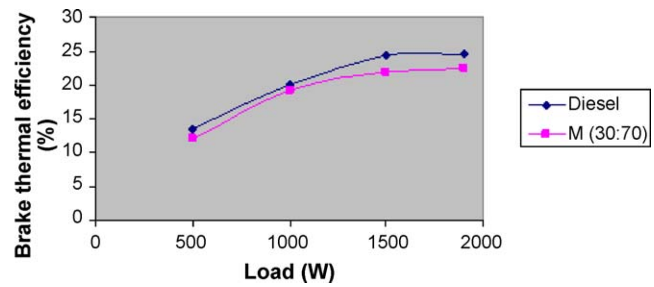

Fig. 4. Variation in BTE with load for different blends of Jatropha oil with methanol.

The variation of brake thermal efficiency of blend of Jatropha oil and methanol is shown in Fig. 4, which indicates that the brake thermal efficiency of blend of Jatropha oil and methanol (22.4%) is almost 2.1% less than that of diesel at full load.

But at the same time it is 3.1% higher than that of blend of Jatropha oil and diesel (21.7%). Blends of Jatropha oil and methanol have lower viscosity and density than SVO and diesel blend. The reduction in viscosity helps to improve the atomization, fuel vaporization and combustion. The thermal efficiency of blends has improved due to faster burning of methanol in the blend. The reason being the rise in the heat release rate due to rapid combustion of methanol by flame propagation. The thermal efficiency has increased compared to raw Jatropha oil and blends of Jatropha oil with diesel.

10. Stability of biodiesel

Biodiesel produced from vegetable oils and other feedstocks have been found to be more susceptible to oxidation owing to the exposure to oxygen of the air and high temperature, mainly, due to the presence of varying numbers of double bonds in the free fatty acid molecules. The chemical reactivity of fatty oils and esters can therefore be divided into oxidative and thermal instability which can be determined by the amount and configuration of the olefinic unsaturation in the fatty acid chains. Many of the plant-derived fatty oils like soyabean and rapeseed contain polyunsaturated fatty acid that are more prone to oxidation. This structural fact is key to the understanding both oxidative and thermal instability. The stability of biodiesel and its blends may comprise these type of stability as given below.

10.1. Storage stability

Storage stability is the ability of liquid fuel to resist change in its physical and chemical characteristics brought about by its interaction with its environment during storage [14].

The customer acceptance, standardization and quality assurance are the key factors for introducing new alternatives of liquid

Initiation: $RH + I \rightarrow R\cdot + IH$

Propagation: $R\cdot + O_2 \rightarrow ROO\cdot$

$ROO\cdot + RH \rightarrow ROOH + R\cdot$

Termination: $R\cdot + R\cdot \rightarrow R\text{-}R$

$ROO\cdot + ROO\cdot \rightarrow$ Stable Products

Fig. 5. Oxidation reaction.

biofuels as biodiesel and its blends into the market and storage stability is one such criteria. The storage stability problem of biodiesel during storage is expected to be more severe than for commercial diesel fuel. The resistance of biodiesel due to oxidative degradation during storage is therefore an important increasingly important issue for the viability and sustainability of alternative fuels.

Stability may be affected by interaction with contaminants, light, factors causing sediment formation, changes in color and other changes that reduce clarity of the fuel [15,16]. Several authors have concluded the long term storage test on biodiesel stability and investigates the effect of physical properties of the fuel with respect to time [17–20,26–28] and it was reported that viscosity, peroxide value, acid value and density of biodiesel increases when stored for 2 years while the heat of combustion decreases [17–21].

10.2. Oxidation stability

10.2.1. Chemistry of oxidation

Oxidation occurs by a set of reactions categorized as initiation, propagation, and termination as shown in Fig. 5.

Fig. 5 shows that first set involves the removal of hydrogen from a carbon atom to produce a carbon free radical. If diatomic oxygen is present, the subsequent reaction to form a peroxy radical is extremely fast, so fast as to not allow significant alternatives for the carbon-based free radical [22,23]. The peroxy free radical is not as reactive as the carbon free radical, but is sufficiently reactive to quickly abstract another hydrogen from a carbon to form another carbon radical and a hydroperoxide (ROOH). The new carbon free radical can then react with diatomic oxygen to continue the propagation cycle. This chain reaction terminates when two free radicals react with each other to yield stable products.

10.3. Thermal stability

Thermal oxidation is defined as the rate of oxidation reaction which increases weight of oil and fat owing to exposure to high temperature (cooking temperature) [24,25].

11. Conclusion

The present study has dealt with the study the prospect of biodiesel from jatropha on India, production of biodiesel from Jatropha oil, performance evaluation of 2 kVA DG set on blends of SVO, blends of biodiesel and blends of SVO with methanol at various loads. The brake thermal efficiency is found higher up to B_{30} in comparison to diesel while BTE of B_{100} (24%) was almost equals to diesel (24.5%) for JOME.

The experiments suggest that biodiesel can entirely replace diesel for IC engine, even though higher amount of B_{100} fuel needs to be utilized and no engine problem was experienced during the course of experimentations.

Jatropha curcas is becoming the future source of biodiesel for India. The planning commission, Government of India, has initiated an ambitious program of growing *jatropha curcas* on waste land for biodiesel production. Among the various oil seeds, *jatropha curcas* has been found more suitable for biodiesel production on the basis of various characteristics. The cultivation of Jatropha is possible under stress condition and the oil of these species having various characteristics is more suitable for biodiesel production. *Jatropha curcas* has been scientifically developed to give better yield and productivity of oil. Jatropha oil has higher cetane no. (51) compared to other oils, which is compared to diesel (46–50) and make it an ideal alternative fuel and requires no modification in the engine. Basic problem with biodiesel is that it oxidized while in contact with environment with respect to time which further lead to increase in fuel viscosity. Research is going on at national as well as international level for controlling the oxidation of biodiesel from edible seeds. However, much effort is required in this area for biodiesel from non-edible seeds also.

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